EROSION AND SEDIMENTATION CONTROL

DESIGN PROCEDURES

The steps in executing a project of erosion and sedimentation control are:

1) Mapping significant erosion/sedimentation problems;

2) Designing land surfaces, drainage channels, erosion and sedimentation control structures;

3) Reshaping land surfaces and channels, and constructing control structures;

4) Revegetating;

5) Monitoring, evaluating, and maintaining remediation.

This section briefly outlines the first two steps -- mapping and design -- as an aide in choosing the appropriate remediation measures. The following sections provide construction guidelines on particular erosion and sedimentation control measures.

Mapping and evaluation must include the disturbed and undisturbed lands and channels both upstream and downstream of planned remediation activities. The geomorphic components are hillslopes, drainage network, stream channels, and geology. The investigation must assess these features with special attention given to gullies and hillslopes. The gullies must be mapped with their length, frequency, and extent on both natural and nearby reclaimed lands. Of primary importance, hillslopes are the sediment production zone. Under conditions of sufficient precipitation, and hillslope gradient and length, unconcentrated runoff becomes concentrated flow, and rills begin to form. As erosion intensifies in the rills, and as hillslope gradient and length increase, rills develop into gullies.

For large projects, design is an iterative process that starts with a design, followed by runoff estimates, hydraulic analysis, and returning to design if the hydraulic analysis shows inconsistencies. Generally, large projects are those where mining or the remediation intersects drainage channels. Typically, this includes most 20th century mines, and 19th century mining districts with concentrated activities.

For small projects, design simply requires some experienced judgement in reshaping impacted areas to stable shapes, and installing small, sometimes hand built, erosion control structures. Generally, small projects are those confined to hillslope areas of unconcentrated runoff. Typically, this includes individual 19th century mining sites.

LANDFORMS

Stable landforms have appropriate shape, high infiltration rates, low sediment yields, low relief, and dense vegetation. The best guide is to replicate characteristics of native landforms by manipulating the length, gradient, and shape of hillslopes, as follows:

* The four basic shapes for hillslopes are uniform, concave, convex, and complex. See Fig. 13. Complex and concave hillslopes are the more stable landforms. Reshaping of landforms should approach these stable profiles.

* Erosion potential increases with increasing hillslope length. Keep hillslope length short by interrupting long hillslopes with terraces, benches, and reverse benches.

* Keep hillslope gradients gentle, never more than 2.5h:1v and preferably less than 3h:1v.

* Increase the density of primary drainage channels.

* In backfills, a subsurface drainage system is often required to prevent subsidence and extreme gullying on steep hillslopes. Subsurface drainage consists of French drains that collect water, and sometimes slope-pipes that carry water to the toe of the hillslope.

Generally, runoff and erosion are estimated with the Rational Method, Soil Conservation Service (SCS) triangular hydrograph technique, and the Universal Soil Loss Equation. First, consult State and local SCS offices for the preferred estimating methods. If no specific guidelines are given by those sources, use SCS engineering manuals.

CHANNELS

For restored channels, the native drainage network must be characterized and replicated for best results. The components include basin gradient, size, and shape; drainage density; channel geometry and lithology. In replicating these components, follow these guidelines:

* Over design assuming sediment loads and infiltration will be different than native conditions.

* Increase drainage density.

* Use native channels as a model for channel geometry (width, depth, shape). Adjust dimensions for estimated higher peak runoff and sediment loads.

* Match channel gradient with native channels, otherwise erosion may develop such as gullying, headcuts, and knickpoints at disturbed/undisturbed boundaries.

* Mimic native channel patterns.

* If necessary to achieve acceptable gradients, wind channels to spread the change in elevation over longer distances.

* Design channel bed characteristics including particle size gradation, wetlands, and revegetation.

Practical limitations on remediation may not lead to stable channel design. Headcuts may form, migrate upstream, induce erosion, and severely impact stability of the restored drainage and landforms. Typically the greatest challenge is to achieve a stable channel gradient, and when this is not feasible engineered structures must be planned to control erosion. Because these engineered structures require continuing maintenance, their use should be minimized. These structures include detention basins and impoundments to settle out sediments, and drop structures to reduce kinetic energy of fast flowing water.

After preliminary design of landform and drainage, the basin hydrology must be evaluated to determine whether design meets the remediation requirements. The cycle of design, runoff estimates, and hydraulic analysis repeats until the remediation requirements match the expected basin hydrology. For expertise on design, hydraulic analysis, and basic hydrology, consult with NPS experts, the local Soil Conservation Service office, or contract engineering services.

REFERENCE: This section paraphrased from Lidstone and Anderson, 1989, p. 478.

TOPSOIL REMOVAL AND STORAGE

DESCRIPTION

Topsoil is generally defined as the A and B horizons of the undisturbed soil profile. These two horizons should be removed and stored separately, and then returned in the same relative position. Topsoil quantity and quality available for reclamation must be determined by site specific evaluations. General guidelines for evaluating specific soil parameters are given under Site Characterization and Monitoring, and additional information may be obtained from local Soil Conservation Service offices and State regulatory agencies.

One of the first activities in mitigating a mine site is salvage of any topsoil that otherwise might be lost in the construction activities. Further, it may necessary to strip soil from other areas for use in reclaiming the mine site. This topsoil recovery exposes topsoil to splash and runoff erosion.

Cost: \$0.40 to \$1.50 per cu yd.

MATERIAL

Table IX indicates soil suitable for reclamation.

TABLE IX

SOIL SUITABILITY FOR RECLAMATION USE

Soil Property	Soil Quality			
	Good	Fair	Poor	Unsuitable
Texture	Sandy loam Loam Silt Loam	Sandy clay loam Silty clay loam Clay loam	Sandy clay Loamy sand Silty clay	Clay 60%
Rock & Gravel (% by volume)	0-10	10-20	20-40	>40
pH	6-8	5-6 8-8.5	4.5-5* 8.5-9**	<4.5 >9
Sodium Absorption Ratio (SAR)	4	4-8	8-16	>16
Electrical Conductivity (mmhos/cm)	3	3-7	7-15	>15

*Check for excessive concentrations of heavy metals.
**Check for excessive boron or lime.

REFERENCE: (USFS, no date, p. 16)

Salvage both topsoil and subsoil if they fall within the good or fair categories. Soils in the poor quality class may also be saved to meet required soil cover depths.

Salvaged soils may show a variety of properties that fall into different suitability classes. For example, a soil may show texture, pH, sodium adsorption ratio, and electrical conductivity in the fair class but rock and gravel content in the poor class. In that case, the soil is classed as poor. Generally, a soil is judged by its lowest individual rating.

Recommended depths of cover soil:

* Where the underlying material is not highly acidic or saline, 12 in. of cover soil is adequate.

* Where the underlying material is highly acidic or saline, up to 48 in. of cover soil is required.

* Where the underlying material is coarse textured or rocky, up to 24 in. of cover soil is required.

After topsoil removal, it also may be necessary to protect the newly exposed surface as described in the sections Reshaping Highwalls and Roads, and Waste Dump Stabilization.

CONSTRUCTION

* Locate topsoil storage close to mine site.

* Choose a storage site that is as level as possible and away from intermittent water courses or gullies.

* Divert upland watershed drainage around topsoil recovery area and storage site with diversion dikes or ditches. Place interceptor diversions below cleared area. These diversions should not have gradients exceeding 2%. Seed or stabilize diversions immediately after construction.

* If diverted water accumulates sediments, first try to eliminate sedimentation by additional mulch, grass, or stabilization. If upland control is inadequate, provide means to settle solids in sediment traps, gravel filters, or filter strips. In some cases, sedimentation basins may be necessary.

* If diverted flow velocity is minimal (less than 1.5 fps), discharge directly into receiving streams; otherwise, install energy dissipators.

* From topsoil recovery area and storage site, clear and grub vegetation greater than 4 in. diameter. Alternatively, shred vegetation and remove with topsoil. Shredded vegetation acts as a mulch.

* Remove soil for storage as indicated by the above table and notes.

* Minimize cleared areas, and phase clearing to reduce unnecessary erosion.

* If the topsoil is stored for more than 2 months, revegetate stockpile with legumes or grasses.

* Reshape and revegetate topsoil recovery areas, storage areas, and erosion control measures after the topsoil operations are complete.

REFERENCES: This section paraphrased from PDER, 1978 p. 8; Thorne, 1987, p. 37; USFS, no date, p. 17.

HILLSLOPE EROSION CONTROL

DESCRIPTION

Hillslopes are the sediment production zone. Under conditions of sufficient precipitation, and hillslope gradient and length, unconcentrated runoff becomes concentrated flow, and rills begin to form. As erosion intensifies in the rills, and as hillslope gradient and length increase, rills develop into gullies.

Erosion from mine sites reaches large rates, up to 300 tons per acre per year. (19.8, p.17) In addition, storm water draining across backfills or mine dumps may saturate the ground, and increase the potential for slides.

Cost: $3,000 to $400,000 per project.

DESIGN GUIDELINES

> The most effective erosion control method is the establishment of dense vegetation cover in as short a time as possible.

Reshaping

* Restore mine sites progressively, exposing as little of the surface as possible.

* For final grading, work from top of hillslope to bottom. Surface should be smooth and without depressions. Unintentional depressions accumulate runoff, and may cause ground instability.

* To minimize erosion, grade during periods of low precipitation, typically summer and fall. Grading may be appropriate in spring and fall when seeding is most successful. Grading should not be done in winter when the ground is frozen.

* Follow surface disturbances with erosion control and revegetation as soon as possible.

Watershed

First estimate the amount of runoff expected as described under Design Procedures, and then design the appropriate erosion and sedimentation structures, as outlined below. Note that additional guidance is given on some of the structures under separate headings.

* Divert upland watershed drainage around disturbed area with diversion dikes or ditches. Place interceptor diversions below the area. These diversions should not have gradients exceeding 2%. Seed or stabilize diversions immediately after construction.

* Leave natural barriers or undisturbed strips of vegetation below disturbed areas to act as filters for surface runoff, and cut flow velocity. See Fig. 12.

* If diverted water accumulates sediments, first try to eliminate sedimentation by additional mulch, grass, or stabilization. If upland control is inadequate, provide means to settle solids in sediment traps, gravel filters, or filter strips. In some cases, sedimentation basins may be necessary.

* If diverted flow velocity is minimal (less than 1.5 ft per sec), discharge directly into receiving streams; otherwise, install energy dissipators to cut velocity.

* Maintain diversion structures until remediation is complete and revegetation is established. Then, grade over structures and plant.

Hillslope Measures

* Disperse water with tracking, furrowing, benching, pitting, waterbars, wattling, and ravel catchers.

  Tracking is used on steep hillslopes, and is the practice of running tracked equipment up and down hillslope. Track grooves reduce and disperse surface runoff. A disadvantage is increased soil compaction from additional passes of equipment.

  Furrows are constructed on contour by ripping with a dozer or by angling dozer blade into hillslope. Safe up to a 2h:1v gradient.

  Benching converts long, continuous hillslopes into a series of ridges and channels. In addition to reducing erosion caused by surface runoff, benches also conserve moisture, and can be designed to provide access to hillslopes for mulching, seeding, and maintenance.

Pitting (dozer basins) is the construction of small water catchment basins, see Fig. 19. Basins catch water and trap eroding sediments. Locate basins in a staggered pattern such that overflow from one basin exits the sides and drains into a lower basin. Basins provide deviations in microclimate that stimulate plant diversity.

Waterbars, wattling, and ravel catchers, see guidance under Handbuilt Hillslope Structures.

* Divert surface runoff with trenches and ditches that parallel hillslope contours.

* Cover bare ground and reduce the opportunity for rainsplash erosion with geotextiles, soil stabilizers, and mulching.

  Soil stabilizers are chemicals that form a crust or protective sheath over soil. They often produce poor results where rainfall is abundant such as the eastern U.S.

REFERENCES: This section paraphrased from PDER, 1978, p. 13; Thorne, 1987, p. 34 & 35; USFS, no date, p. 17.

RIPRAP DROP STRUCTURES

DESCRIPTION

Where a stable drainage gradient is not feasible, riprap drop structures provide an efficient means to lower a channel, dissipate kinetic energy of water, and prevent erosion. As shown in Fig. 20, riprap drop structures consist of a transitional entrance, sloped drop section, and transitional exit or stilling basin. Construction involves clearing and grubbing, compaction, and placing filter fabric, gravel, and riprap.

Cost: $30 to $90 per cu yd.

MATERIALS

Riprap: Sized to remain immobile under a specified (100 yr, 24 hr) runoff event. Well-graded, hard, durable, and angular on all sides.

Gravel: See NPS specifications.

Filter fabric.

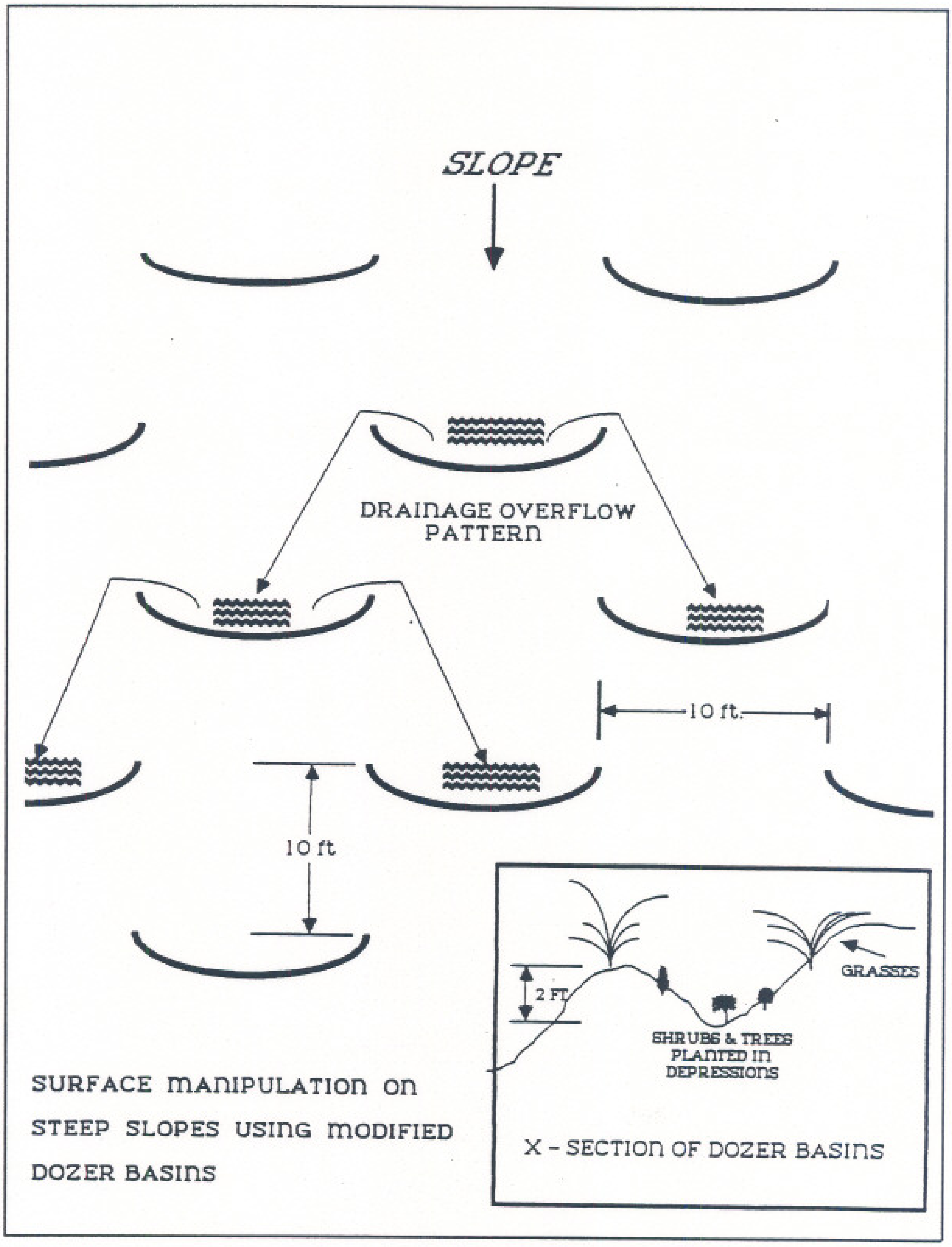
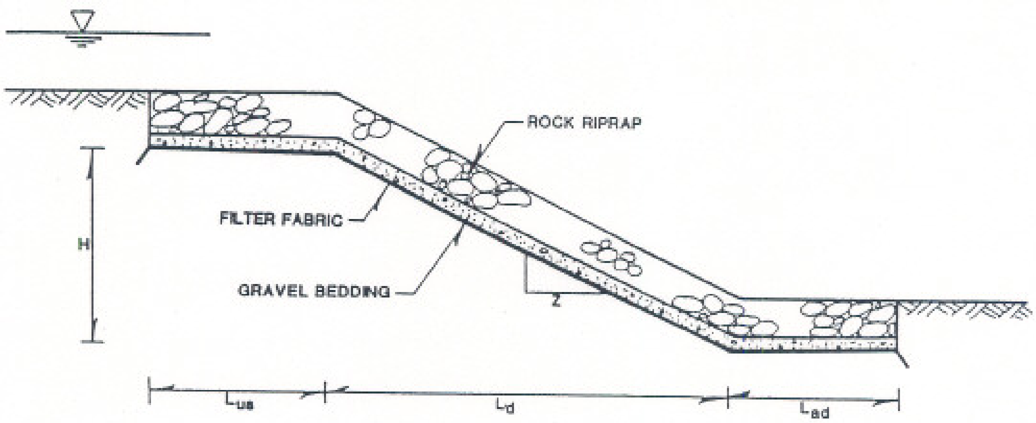


Figure 19. Pitting
(Lawson, 1990, p. 223)



H – DROP HEIGHT

L_{us} – LENGTH OF UPSTREAM TRANSITION

L_d – LENGTH OF DROP

L_{ds} – LENGTH OF DOWNSTREAM TRANSITION

Z – SLOPE OF THE DROP

Figure 20. Riprap Drop Structures
(Lidstone, 1989, p. 490)

Place riprap such that there is no segregation into size fractions.

REFERENCE: This section paraphrased from Lidstone and Anderson, 1989, p. 489.

GEOLOGIC DROP STRUCTURES

DESCRIPTION

Given the right conditions, geologic drop structures can replace or supplement engineered structures. Geologic drop structures use erosionally resistant rock formations where they outcrop in a drainage channel. A thorough review of site geology prior to channel design can save thousands of dollars in engineered drop structures and improve channel longevity. Construction involves drilling, blasting, and earthmoving.

Cost: $1.00 to $1.50 per cu yd of earthmoving.

MATERIALS

Resistant rock formation.

DESIGN GUIDELINES

Layout the geologic drop structure similar to the riprap drop structure with transitional entrance, slope section, and transitional exit or stilling basin. All three elements should be confined within the resistant rock formation to ensure against erosion. Typically the gradient of the slope section ranges from 3h:1v to 4h:1v.

REFERENCE: This section paraphrased from Lidstone and Anderson, 1989, p. 489.

DIVERSION DITCHES

DESCRIPTION

Uncontrolled or misdirected water causes unacceptable soil losses, extreme gullying, and often polluted drainage where water flows over mine wastes. Ditches intercept and divert water around disturbed areas, and control water during reshaping and remediation of mining disturbances.

Cost: $3,000 to $300,000 per project.

DESIGN GUIDELINES

Although many factors influence ditch design, the following general criteria are adequate for most applications:

* Design for 24 hr, 10 to 25 yr rainfall events.
* Use V-shaped ditches in temporary applications for their relative ease in design, construction, and maintenance.
* Use trapezoidal or parabolic ditches for permanent applications, and perform complete engineering design.
* Adjacent to roads, design ditch sides at 4h:1v or flatter except in extreme restrictive conditions. For vehicle safety, the road side should not exceed a 2h:1v gradient.
* Ditch sides not adjacent to a road may have a gradient that varies with the material encountered. In rock, the gradient may approach vertical; in erodable material, a 2h:1v gradient or flatter.
* Locate ditches in undisturbed earth or rock; avoid placing ditches through fill areas.
* Protect toe of fill slopes with interceptor ditches.
* Ditches should not discharge over fill slopes. In fill situations, convey discharge away with pipes or lined ditches.
* At discharge points, provide erosion protection as shown in Fig. 21, if flow velocity exceeds Soil Conservation Service recommended maximums.

First estimate the amount of runoff expected as described under Design Procedures, and then design channel gradient, ditch cross section, and ditch depth, as follows.

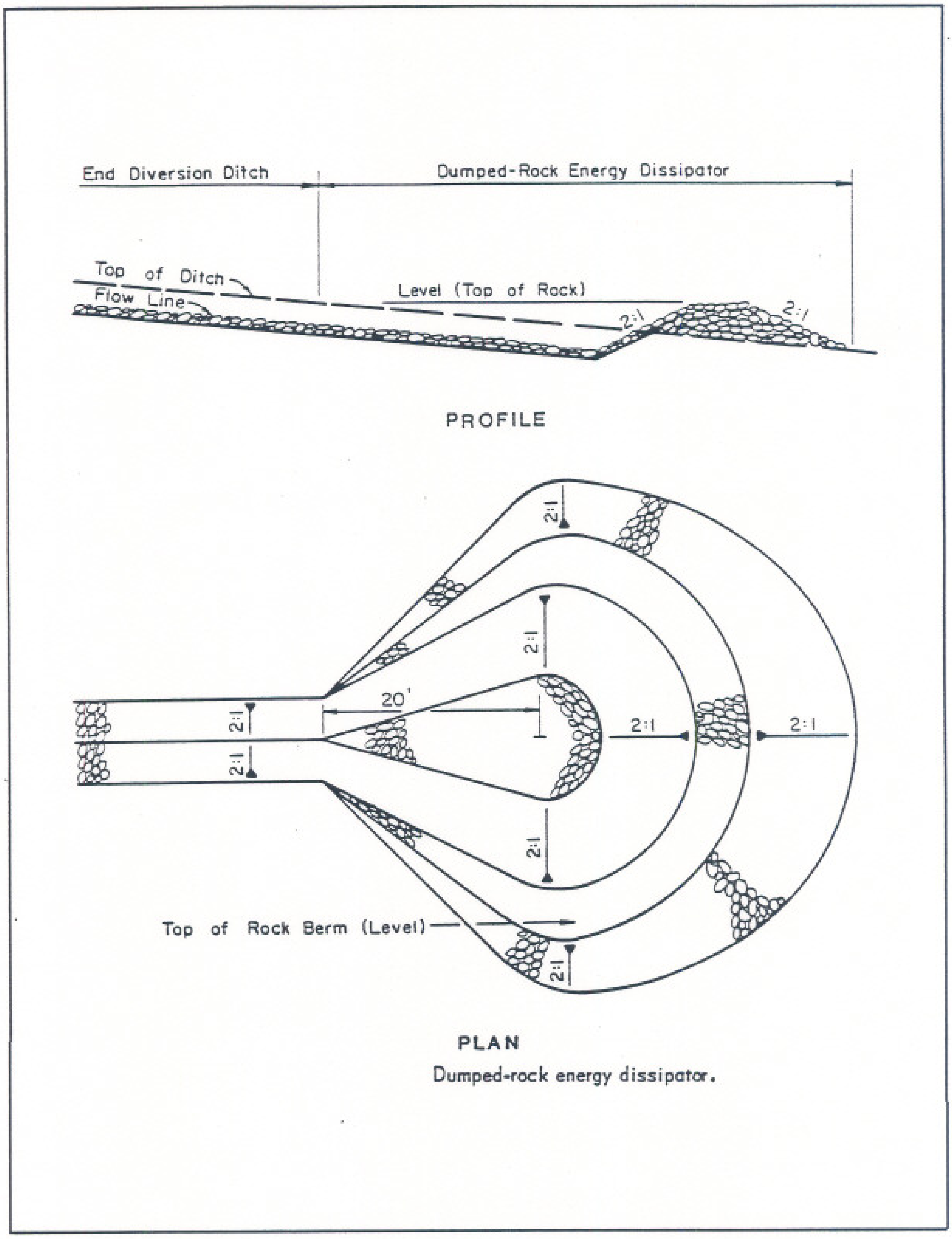


Figure 21. Erosion Control at Discharge Points
(IC 8758, 1977, p. 46)

Channel Gradient

Generally ditches intended to intercept and divert sheet runoff are designed with a 0.5% gradient. Where ditches are required with steeper gradients in erodable soils, protect against excessive erosion (Fig. 22):

* Ditch gradient 0% to 3%, construct without liner except in extremely erodable material such as sand, or easily weathered shales and silts.

* Ditch gradient 3% to 5%, seed ditch and protect with jute matting until a substantial grass lining is established.

* Ditch gradients over 5%, line ditch with rock to a height no less than 0.5 ft above the expected high water level.

* Add drop structures to reduce channel gradients.

Ditch Cross Section

With the design criteria given above, choose appropriate gradients for the ditch sides given the type of ground encountered and position next to roads.

Ditch Depth

With runoff in cubic feet per second, determine the required water depth from Table X. Find the applicable ditch cross section, enter the table under ditch gradient, and follow the column down to the estimated runoff. Then, follow the row of that runoff to the extreme left column which contains the required ditch depth. Make the following applicable depth adjustments:

* Add 0.5 ft to the water depth for freeboard.

* Where the ditch is lined with grass, add 0.5 ft.

* Where the ditch is lined with rock, depth is measured to the top of the rock surface.

Perform ditch design in segments for each change in 1) ditch gradient, 2) additional runoff contributed by contiguous areas, and 3) type of ground.

REFERENCES: This section paraphrased from Kaufman & Ault, 1977, p.39; PDER, 1978 p. 53: USBLM, 1985, p. 28.

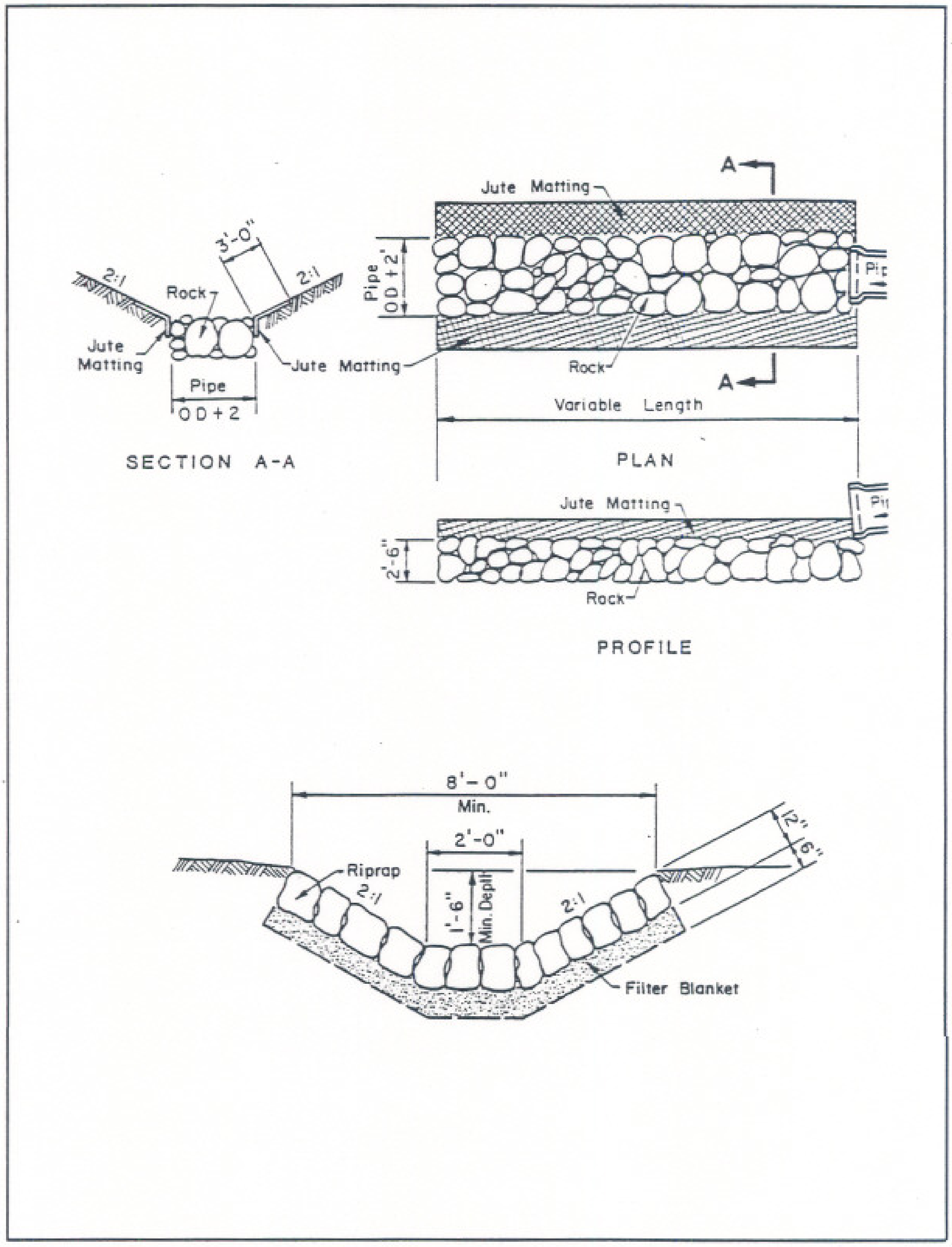


Figure 22. Erosion Protection of Ditches
(IC 8758, 1977, p. 46)

Table X

Water-volume capacity for various V-ditch configurations, cubic feet per second

Depth of water (feet)	Slope, percent 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Grass cover			Jute matting					Dumped Rock											
0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
.4	.4	.5	.6	.6	.7	.5	.5	.5	.6	.6	.6	.7	.7	.7	.8	.8	.8	.8	.8	.9
.6	1.1	1.6	1.7	1.9	2.1	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2 1	2.1	2.2	2.3	2.4	2.4	2.5	2.6
.8	2.5	3.5	3.6	4.1	4.6	3.0	3.3	3.5	3.7	3.9	4.1	4.3	4.5	4.6	4.8	4.9	5.1	5.2	5.4	5.5
1.0	4.5	6.3	6.5	7.5	8.3	5.5	5.9	6.3	6.7	7.1	7.4	7.8	8.1	8.4	8.7	9.0	9.2	9.5	9.8	10.0
1.2	7.3	10.3	10.5	12.1	13.6	8.9	9.6	10.3	10.9	11.5	12.1	12.6	13.1	13.6	14.1	14.5	15.0	15.4	15.9	16.3
1.4	11.0	15.5	15.8	18.3	20.4	13.4	14.5	15.5	16.4	17.3	18.2	19.0	19.8	20.5	21.2	21.9	22.6	23.3	23.9	24.5
1.6	15.6	22.1	22.6	26.1	29.1	19.2	20.7	22.1	23.5	24.7	25.9	27.1	28.2	29.3	30.3	31.3	32.2	33.2	34.1	35.0
1.8	21.4	30.3	30.9	35.7	39.9	26.2	28.3	30.3	32.1	33.8	35.5	37.1	38.6	40.0	41.4	42.8	44.1	45.4	46.6	47.8
2.0	28.3	40.0	40.9	47.2	52.8	34.7	37.5	40.0	42.5	44.8	47.0	49.0	51.0	53.0	54.8	56.6	58.4	60.1	61.7	63.3

Depth of water (feet)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0.2	0.1	0.2	0.2	00.2	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3
.4	.8	1.1	1.1	1.3	1.5	1.0	1.0	1.1	1.2	1.2	1.3	1.4	1.4	1.5	1.5	1.6	1.6	1.7	1.7	1.7
.6	2.3	3.3	3.3	3.8	4.3	2.8	3.0	3.3	3.4	3.6	3.8	4.0	4.1	4.3	4.5	4.6	4.7	4.9	5.0	5.1
.8	4.9	7.0	7.1	8.2	9.2	6.1	6.5	7.0	7.4	7.8	8.2	8.6	8.9	9.3	9.6	9.9	10.2	10.5	10.8	11.1
1.0	9.0	12.7	12.9	14.9	16.7	11.0	11.8	12.7	13.4	14.2	14.9	15.5	16.1	16.8	17.3	17.9	18.5	19.0	19.5	20.0
1.2	14.5	20.6	21.0	24.2	27.1	17.8	19.2	20.6	21.8	23.0	24.1	25.2	26.2	27.2	28.2	29.1	30.0	31.7	31.7	32.5
1.4	21.9	31.0	31.6	36.5	40.9	26.9	29.0	31.0	32.9	34.7	36.4	38.0	39.5	41.0	42.5	43.9	45.2	46.5	47.8	49.0
1.6	31.3	44.2	45.1	52.1	58.3	38.3	41.4	44.2	46.9	49.5	51.9	54.2	56.4	58.5	60.6	62.6	64.5	66.3	68.2	69.9
1.8	42.8	60.5	61.8	71.3	79.7	52.4	56.6	60.5	64.2	67.7	71.0	74.1	77.1	80.0	82.9	85.6	88.2	90.8	93.3	95.7
2.0	56.6	80.1	81.7	94.4	105.5	69.4	74.9	80.1	84.9	89.5	93.9	98.1	102.1	105.9	109.7	113.3	116.7	120.1	123.4	126.6

Depth of water (feet)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
2.2	73.0	103.2	105.3	121.6	136.0	89.4	96.5	103.2	109.5	115.4	121.0	126.4	131.5	136.5	141.3	145.9	150.4	154.8	159.0	163.2
2.4	92.0	130.1	132.7	153.3	171.4	112.6	121.7	130.1	138.0	145.4	152.5	159.3	165.8	172.1	178.1	183.9	189.6	195.1	200.4	205.7
2.6	113.8	160.9	164.2	189.7	212.0	139.4	150.5	160.9	170.7	179.9	188.7	197.1	205.1	212.9	220.4	227.6	234.6	241.4	248.0	254.5
2.8	138.6	196.0	200.0	231.0	258.3	169.7	183.3	196.0	207.9	219.1	229.8	240.0	249.9	259.3	268.4	277.2	285.7	294.0	302.1	309.9
3.0	166.5	235.5	240.3	277.5	310.3	203.9	220.3	235.5	249.8	263.3	276.1	288.4	300.2	311.5	322.4	333.0	343.3	353.2	262.9	372.3
3.2	197.7	279.6	285.4	329.5	368.4	242.1	261.5	279.6	296.5	312.6	327.8	342.4	356.4	369.9	382.8	395.4	407.6	419.4	430.9	442.1
3.4	232.3	328.5	335.3	387.2	432.9	284.5	307.3	328.5	348.4	367.3	385.2	402.3	418.8	434.6	449.9	464.6	478.9	492.8	506.3	-
3.6	270.4	382.5	390.3	450.7	503.9	331.2	357.7	382.5	405.7	427.6	448.5	468.4	487.5	505.9	-	-	-	-	-	-
3.8	312.3	441.6	450.7	520.4	581.9	382.4	413.1	441.6	468.4	493.7	517.8	-	-	-	-	-	-	-	-	-
4.0	357.9	506.2	516.6	596.5	666.9	438.4	473.5	506.2	-	-	-	-	-	-	-	-	-	-	-	-

Depth of water (feet)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
2.2	109.5	154.8	158.0	182.4	204.0	134.1	144.1	154.8	164.2	173.1	181.5	189.6	197.3	204.8	212.0	218.9	225.6	232.2	238.6	244.7
2.4	138.0	195.1	199.1	229.9	257.1	169.0	182.5	195.1	206.9	218.1	228.8	239.0	248.7	258.1	267.2	275.9	284.4	292.7	300.7	308.5
2.6	170.7	241.4	246.4	284.5	318.1	209.1	225.8	241.4	256.0	269.9	283.1	295.7	307.7	319.3	330.6	341.4	351.9	362.1	372.0	381.7
2.8	207.9	294.0	300.1	346.5	387.4	254.6	275.0	294.0	311.8	328.7	344.7	360.1	374.8	388.9	402.6	415.8	428.6	441.0	453.1	464.9
3.0	249.8	353.2	360.5	416.3	465.4	305.9	330.4	353.2	374.7	394.9	414.2	432.6	450.3	467.3	483.7	499.5	-	-	-	-
3.2	296.5	419.4	428.0	494.2	552.6	363.2	392.3	419.4	444.8	468.9	491.8	513.6	-	-	-	-	-	-	-	-
3.4	348.4	492.8	502.9	580.7	649.3	426.8	460.9	492.8	522.7	-	-	-	-	-	-	-	-	-	-	-
3.6	405.7	573.7	585.5	676.1	755.9	496.8	536.6	-	-	-	-	-	-	-	-	-	-	-	-	-
3.8	468.4	622.4	676.1	780.7	872.8	573.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4.0	536.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Kaufman and Ault, 1977, p. 41

CULVERTS

DESCRIPTION

Culverts are efficient and effective in conveying free-flowing drainage away from erosional areas. Full section culverts are used for conveying water through fill areas or under roads, and half sections are used to line surface channels either permanently or temporarily during construction.

Design considerations include location, sizing, installation, and inlet/outlet controls.

Cost: $30 to $60 per foot installed.

MATERIALS

Corrugated steel pipe: For the majority of culvert installations, this type of pipe is relatively light, high strength, readily available, and easily adapted to a variety of situations. Highly acidic conditions may preclude steel, in which case substitute PVC or concrete pipe.

CONSTRUCTION

Design

* Design for 24 hr, 10 to 25 yr rainfall events.

* Minimum 18 in. diameter, smaller culverts are difficult to clean and maintain.

* Design culverts for minimum impact on aquatic life:

  ** Perform construction during the time of year when impact is least.

  ** Use open bottom shapes if it is necessary to maintain character of streambed.

  ** For closed bottom culverts, install culvert with maximum 0.5% gradient, place invert 6 in. below natural gradient, and fill bottom with rock and gravel.

  ** Along roads, provide ditch relief as required by State standards. If there are no regulations regarding culvert spacing, use the following:

Road Grade (%)	Culvert Spacing Not To Exceed (ft)
0 - 3	1,000
3 - 6	800
6 - 9	500
> 10	300

Use Fig. 23 to determine pipe sizes for estimated flows in the following steps:

1. Enter graph from left side with required maximum flow in cubic feet per second (cfs).

2. Follow entry point horizontally to intersection with diagonal line.

3. From intersection, drop down vertically to pipe diameter axis, and read required dimension.

Example: 25 cfs requires a 32 in. pipe diameter.

This dimension represents a full flowing pipe without any water backup at the inlet. Generally, design pipe diameter to accept maximum flow without creating water backup. However, in some cases (temporary installations), it may be desirable to specify a smaller, less expensive pipe, and allow a small backup of water. Dashed lines on the chart provide backup head for restricted pipe diameters. Determine the backup head as follows:

1. Dashed lines are labeled with backup head.

2. Follow entrance capacity horizontally to intersection with a curved dashed line, and then down to required pipe diameter. There may be more than one intersection, choose the desired head.

Example: 25 cfs and backup head of 4 ft requires a pipe diameter of 21 in.

Installation

* Minimum recommended cover over a culvert is 12 in. or one half culvert diameter, whichever is greater.

* Where heavy earthmoving equipment passes over culvert, minimum cover should be 2 ft for vehicles under 100,000 lb in weight, and 3 ft for heavier vehicles.

* To provide a stable culvert base, tamp fill in 4 in. layers from bottom of trench to 2 to 3 ft over culvert.

* To minimize sedimentation and erosion, align culverts with natural channel and maintain natural gradient.

* For laterals or road crossings, skew culvert to form an entrance angle of 25^{o} to 60^{o} with approach ditch, and increase gradient slightly above that of ditch to minimize sedimentation in culvert.

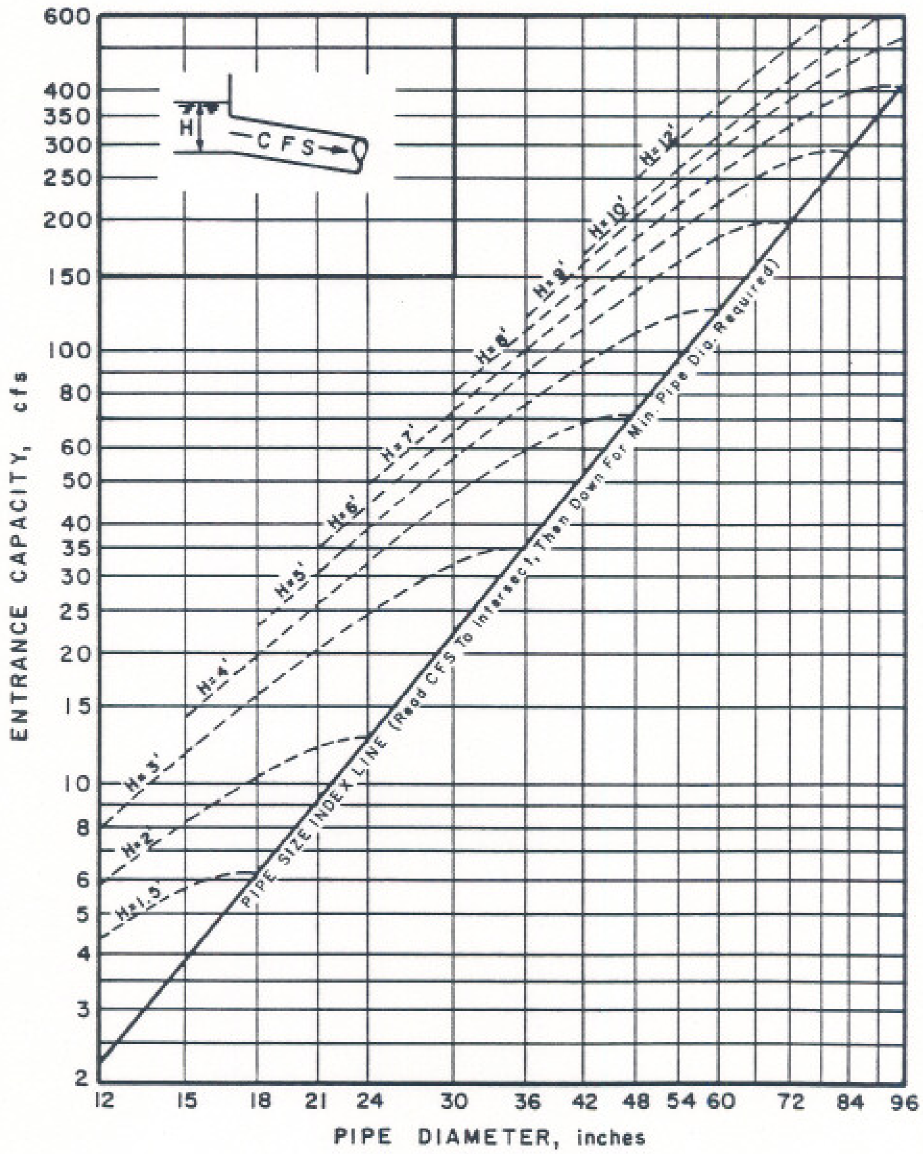


Figure 23. Culvert Capacity
(Kaufman & Ault, 1977, p. 44)

* As necessary, protect culverts from debris with deflectors, racks, cribs, raisers, basins, or spillways.

Inlet/Outlet

At all culvert inlets, construct a protective headwall of stable nonerodable material. At all culvert outlets, install drop structures, energy dissipators, flared ends, headwalls, riprap, paving, or beveled ends, as described under Ditches and Hand Built Drop Structures. Additional guidelines:

* Flow from culverts must never be discharged over a fill slope. In fill situations, convey discharge away by extending culvert or provide ditches lined with nonerodable material.

* At the discharge, provide erosion protection where flow velocity exceeds Soil Conservation Service recommended maximums.

The Soil Conservation Service and many states have regulations specifying erosion and sediment control devices for storm drains. Contact these organizations for requirements that apply to the local situation.

REFERENCES: This section paraphrased from Kaufman & Ault, 1977, p. 39 & 42; USBLM, 1985, p. 28.

SEDIMENTATION AND TREATMENT BASINS

DESCRIPTION

Sedimentation and treatment basins are used to settle solids eroded from land disturbances, and to neutralize acid mine drainage. See Fig. 24.

Cost: $10,000 to $500,000 per project.

CONSTRUCTION

Design requires qualified geotechnical engineering. Integrity of the basin must be insured through adequate design and construction of the foundation, banks, liner, and the normal and emergency spillway or standpipe. Following guidelines list requirements for geotechnical engineering.

Design

* Generally a minimum of two basins, in series, are required to receive runoff and settle solids.

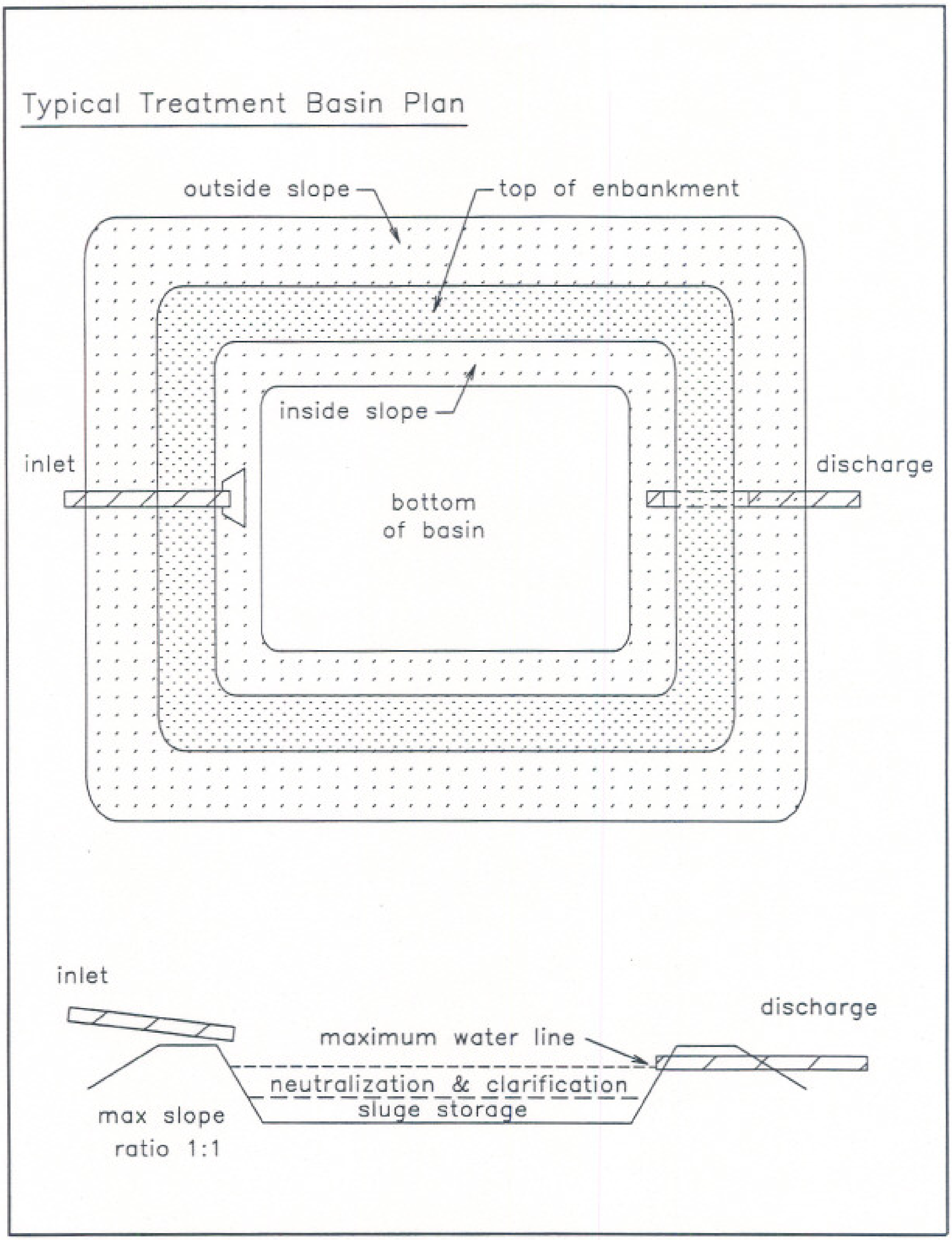


Figure 24. Treatment Basin
(PDER, 1978, p. 58)

* Specify minimum retention time (6 hr*), and design storm event (24 hr, 100 yr*). Check with Soil Conservation Service, State and local agencies for appropriate design criteria.

* Design capacity on the maximum watershed area.

  $V = Sum(A_i \times C_i)(I)(1 + SF)$

  where : V is volume in cu ft.

  A is watershed area in sq ft.

  C is portion of rainfall not absorbed by soils (runoff):
  C = 0.50 for open pit,
  C = 0.30 for undisturbed area,
  C = 0.25 for backfill area,
  Note: Clayey soils may require higher runoff coefficient.

  i is index for subareas in watershed including open pit, undisturbed area, and backfill area.

  I is rainfall (ft per day) x detention time (0.25 day).

  SF is sediment factor
  SF = 0.33 for primary basin,
  SF = 0.20 for secondary basins.

* Specify minimum freeboard (2 ft*) to prevent overspilling.

* Specify maximum (1h:1v*) bank side slopes to control erosion and maintenance.

* For acid mine drainage, collect water in a sump as near source as possible, pump and pipe to treatment basin to minimize infiltration of pollution.

* For treatment basins, control leakage with 1) an impervious foundation blanket and leak collection system, and 2) an inside composite liner made up of clay, asphalt, plastic, or other suitable material.

* Provide sufficient capacity to settle solids by adding additional volume, SF in the above formula (1/3 for primary basin, 1/5 for secondary basins*).

* Design top of bank wide enough to allow repairs (typically width of backhoe or dragline used to clean out sediments).

* Discharges must meet applicable Federal and State effluent standards.

Location

* Locate basins to protect against erosion and breakthroughs from water courses.

* Locate basin to minimize channel gradient between basin discharge and native channel. See Ditches.

* Do not locate basins on steep slopes, poorly drained areas, or bedrock.

* Check for and do not locate basins near underground openings, mine subsidence, sink holes, oil, gas or water wells, and open fractures or joints.

Erosion Control

* Clear and grub all vegetation before construction.

* Use well-graded fill for banks, and compact to reduce void space and increase stability.

* Avoid acid-bearing material in constructing banks.

* Vegetate outslopes to reduce runoff velocity. Grasses are preferable to legumes because they allow inspection for cracks.

* Install drop structures, and riprap basin discharge and channel to minimize erosion.

Maintenance

* Clean sediment from basins when it reaches two thirds of design load.

* Check structure regularly for cracks, rills, piping, leakage, or other signs of instability.

* Maximum erosion generally occurs at outslope toes. Place riprap if toe erosion becomes a problem.

* Other evidence of instability usually requires the expertise of a geotechnical expert.

REFERENCE: This section paraphrased from PDER, 1978, p. 5 & 58.

HANDBUILT HILLSLOPE STRUCTURES

DESCRIPTION

Labor intensive erosion control techniques involve contour terracing structures that disperse concentrated runoff and cause deposition of eroded sediment. The techniques include contour trenches, ditches, water bars, whattling, and ravel catchers. See Fig. 25. They are intended for use in remote areas and small remediation projects.

If contour structures are not absolutely level, they may actually collect and concentrate runoff, and cause more erosion than they control. In this case, area treatments such as mulching should be substituted.

> Cost: $0.50 (trenches) to $5.00 (whattling and ravel boards) per lineal ft.

Contour Trenches

Contour trenches are discontinuous ditches dug on contour. They act as small reservoirs to catch runoff before it concentrates and erodes the surface into rills and gullies. Trenches also stimulate infiltration. Typical trenches are 10 ft long, spaced 5 ft apart on contour.

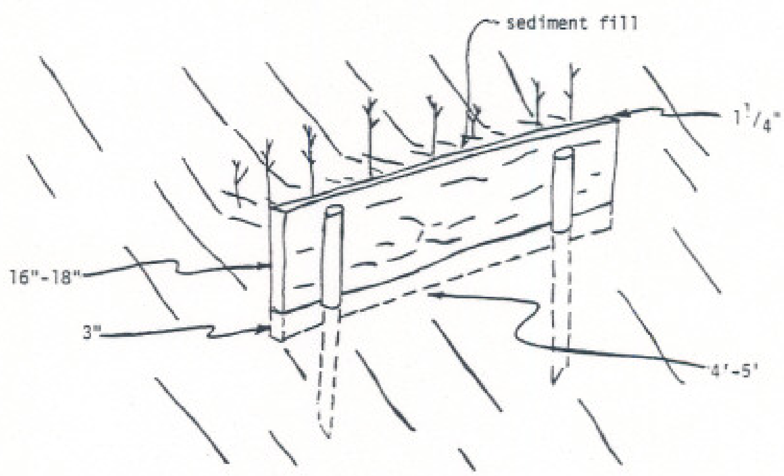
Ditches

Hand dug ditches are used to drain wet hillslopes and divert runoff to stable areas. They are generally shallow compared to those excavated by earthmoving machinery. Ditches grade gently (0.5%) in direction of discharge, and must not become steep enough to cause erosion. When gradients exceed 3%, install drop structures or energy dissipators. In swampy areas, etch feeder channels into soil to drain standing water and saturated soils toward ditch.

Waterbars

Waterbars divert runoff from bare areas to vegetated areas or areas where flow is less apt to cause erosion. Waterbars should abut upslope bank, and grade gently (0.1%) toward discharge. Final dimensions must not allow runoff to flow over top of waterbar. At discharge end, place a 3 ft long energy dissipator of rock or slash.

Contour Trenches



Ravel Catchers

Figure 25. Hand-built Hillslope Structures
(Weaver, 1987, p. B10-18)

Whattling

Wattles are bundles of flexible twigs and branches tied together. Wattling is the practice of placing wattles in contour trenches or staking them on hillslopes to create terraces. After placement, whattles are partially covered with soil. Wattles retard erosion, and revegetate bare hillslopes when using sprouting species.

Bundles may vary in length, but must taper at the ends. To achieve the taper, cut half the stems 1.5 ft longer than average. Alternate stems in bundle so that half the butts are in each end. Compress and tie bundles on 15 in. centers with two wraps of binding twine and non-slipping knots. Finished bundles should be approximately 8 in. diameter.

For sprouting wattles, select live, sprouting species native to the site such as willows (Salix spp.) or coyote brush (Baccharis). Stem butts should not be more than 0.5 in. diameter. Prepare and place bundles preferably on the same day, and not more that one day after cutting stems. Keep bundles covered and wet until placed.

Ravel Catchers

Ravel catchers are boards, dug slightly into the hillside on contour. They catch and store ravel during dry seasons and runoff during wet periods. They also can be backfilled with fertile soil for protected planting sites.

Ravel boards are at least 1.25 in. thick, 16 to 18 in. wide, and 4 to 5 ft long. To install, dig trench a minimum 3 in. deep the length of the board. Place board in trench vertically on a long end, and anchor with wood stakes.

OTHER MATERIALS

Energy dissipators: Hard, durable, and angular rock, 5 to 6 in. diameter. Alternatively, slash with no pieces larger than 12 in. diameter and 24 in. long.

Stakes: Wood greater than 1.25 in. diameter and 24 in. long.

GENERAL CONSTRUCTION GUIDELINES

* Gradient for contour structures must be level. Stake out structure with Abney level, string level, or similar device.

* Design trench, ditch, and trough dimensions (width, depth, and length) for soil infiltration rates and expected short duration, peak rainfall events (24 hr, 20 yr).

* Excavate trenches, ditches, and troughs a minimum of 8 in. into substrate with a minimum top width of 12 in.

* Trenches, ditches, and troughs must be free and clear of vegetation, soil, and rocks that impede flow.

* Place any excavated earth in a berm on downslope side of structure to provide freeboard and increase capacity.

* Compact berms and backfill with hand tamp, shovel, or feet.

* On hillslopes, space contour structures on approximately 3 ft. centers. Arrange structures in a staggered pattern.

* Stake whattles or ravel boards in place on downslope side on minimum 36 in. centers. In addition, drive at least one stake at overlap of bundles or boards.

* Drive stakes at least 15 in. or until refusal. In tight soils, drive pilot holes with steel bars.

* Work should progress in a direction that minimizes soil compaction and damage to structures.

REFERENCE: This section paraphrased from Weaver et al, 1987, p. B-8.

HANDBUILT DROP STRUCTURES

DESCRIPTION

Handbuilt drop structures are used to protect small stream channels from erosion. Checkdams arrest downcutting, and rock armour arrests both downcutting and lateral channel erosion. In general, hand built structures are effective in drainage areas less than 25 acres or as long as flows do not exceed the capacity of dam spillways or the energy to move rocks.

ROCK ARMOUR

Rock armour is placed in small streams, gullies, ditches, or other expected water channels to increase turbulence and energy dissipation, slow water velocity, and eliminate scour of channel banks and beds. See Fig. 26.

Cost: $0.50 (w/o securing) to $2.50 (w/ securing) per sq ft.

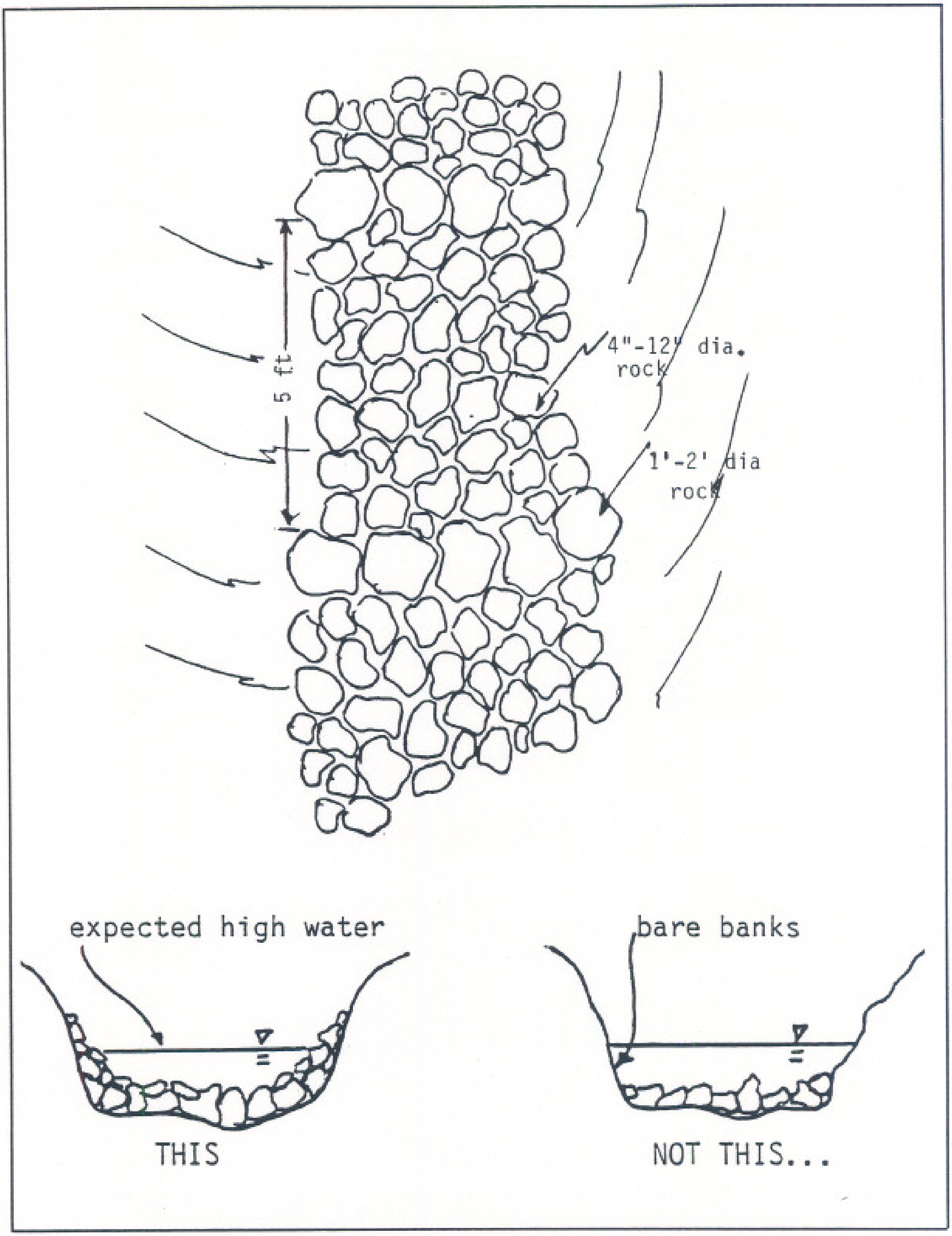


Figure 26. Rock Armor
(Weaver, 1987, B25)

Construction Guidelines

* Design for 24 hr, 20 yr rainfall events.

* For new channels, excavate bottom slightly concave.

* Line channels well above expected high water level to protect against bank cutting.

* Size rocks and secure such that peak flows do not remove armour. For hand labor, maximum size rock is approximately 18 in. diameter.

CHECKDAMS AND OTHER DROP STRUCTURES

Checkdams are placed in streams or gullies to raise channels and drop flow onto energy dissipators. See Fig. 27. Sediment fills space behind checkdams, and stabilizes adjacent bank. Design checkdams such that entire runoff flows through spillway, and waterfall does not undermine checkdams on downstream side.

Cost: $20 to $400 each.

Submerged spillways are checkdams placed with spillway set at streambed level. Submerged spillways are applicable in broad channels with shallow, poorly defined banks and rock bottoms.

Alternatives to checkdams include 1) rock armour which can be built up to form checkdams, 2) tightly bound bundles of boughs for very small streams, and 3) water ladders. Generally water ladders have small capacity, and are expensive and difficult to build in remote areas.

Materials

Boards: Water resistant (redwood, cedar) 1 in. thick for lengths up to 6 ft, 1.25 in. thick for lengths 6 ft to 10 ft.

Anchors: Reinforcing steel (No. 5 or 6 rebar).

Construction Guidelines

* Locate checkdam perpendicular to channel to prevent concentrating flow at either bank.

* Key checkdam into banks a minimum 6 in. and channel bottom a minimum 3 in.

* In a series of checkdams, place lowest checkdam first in nonerodable bedrock or against immovable boulders. Locate next upstream checkdam so that sediment fill of lower checkdam abuts base of upper checkdam. Locate with a line level from spillway.

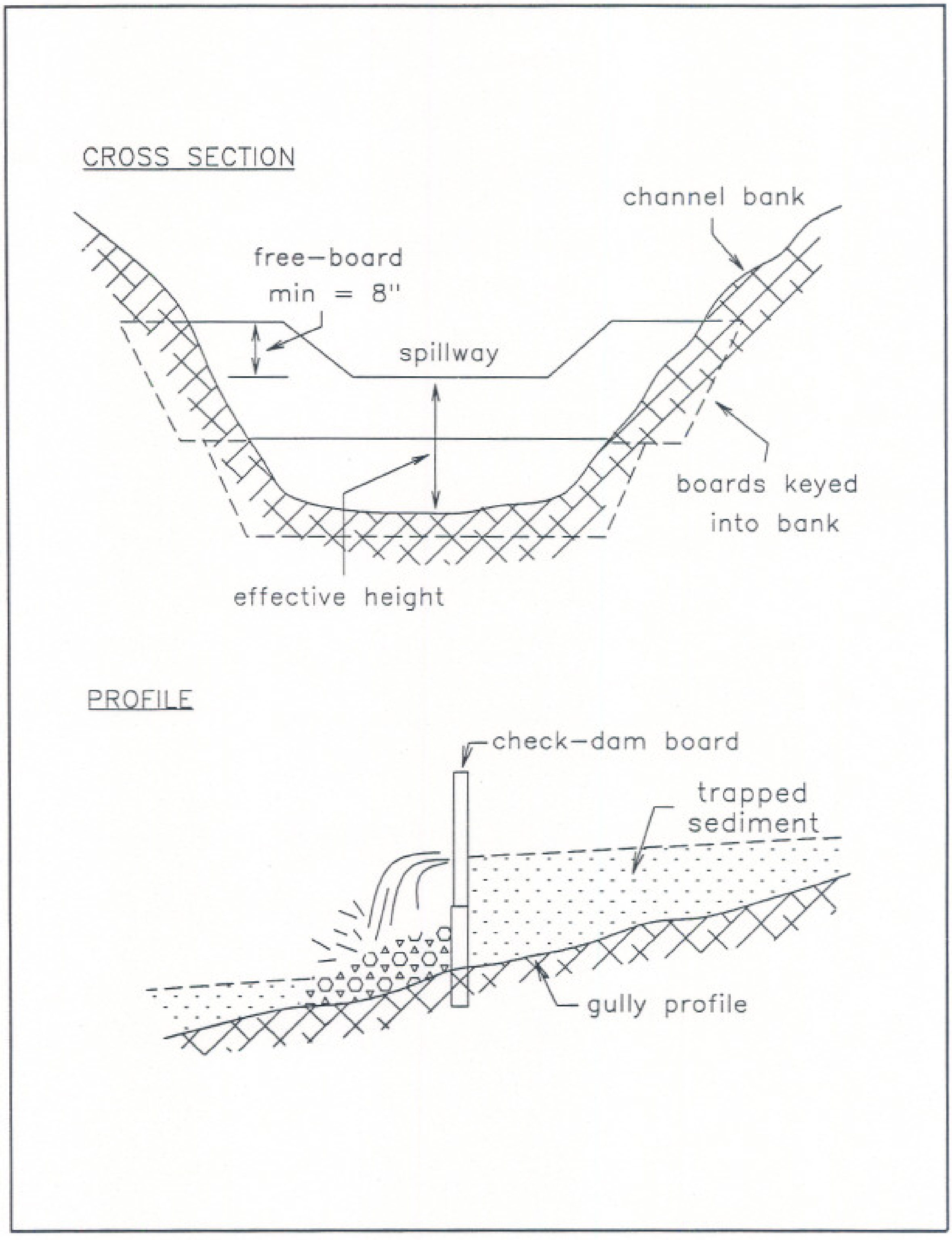


Figure 27. Check Dams
(Weaver et al., 1987, B28-30)

* Design freeboard height and width a minimum of 8 in. on both sides of spillway.

* Design effective height (bottom of channel to spillway) greater than 8 in. and maximize whenever possible.

* Total height equals effective height plus freeboard, and should not exceed 40 in.

* Use two boards to attain total height. Place widest board on top. Spillway notch must not cut through entire width of board.

* Design spillways for 24 hr, 20 yr rainfall events. Use trapezoidal shape, and adjust effective height and side angles to pass the design flow. Spillway must not be so wide that water impacts banks.

* Anchor checkdams with a minimum of 4 rebars driven 2 ft into channel or until refusal. Rebar must be long enough to extend out of channel and support checkdam a minimum 3/4's of its height.

* Place rock armour downstream of checkdam for a width greater than the spillway, and a minimum distance of 1.5 times effective height of checkdam. Slash may be substituted for rock, but must be anchored. There should be no gap between armour and dam.

REFERENCE: This section paraphrased from Weaver et al, 1987, p. B-24.